AD-A138 644 A NOVEL X-RAY BACKLIGHTING METHOD FOR RAYLEIGH-TAYLOR INSTABILITY MEASURE..(U) NAVAL RESEARCH LAB WASHINGTON DC J GRUN ET AL. 17 FEB 84 NRL-MR-5237 1/1

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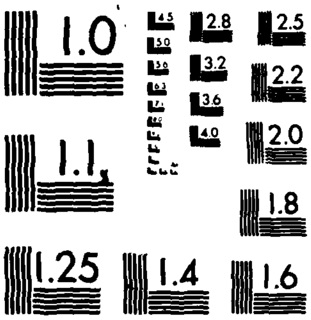

MICROCOPY RESOLUTION TEST CHART
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REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED

1b. RESTRICTIVE MARKINGS:

2a. SECURITY CLASSIFICATION AUTHORITY:

2b. DECLASSIFICATION/DOWNGRADING SCHEDULE:

3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S): NRL Memorandum Report 5237

5. MONITORING ORGANIZATION REPORT NUMBER(S):

6a. NAME OF PERFORMING ORGANIZATION: Naval Research Laboratory

6b. OFFICE SYMBOL *(If applicable)*:

6c. ADDRESS *(City, State and ZIP Code)*: Washington, DC 20375

7a. NAME OF MONITORING ORGANIZATION:

7b. ADDRESS *(City, State and ZIP Code)*:

8a. NAME OF FUNDING/SPONSORING ORGANIZATION: U.S. Department of Energy

8b. OFFICE SYMBOL *(If applicable)*:

8c. ADDRESS *(City, State and ZIP Code)*: Washington, DC 20545

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER:

10. SOURCE OF FUNDING NOS.

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.
			47-0859-0-4

11. TITLE *(Include Security Classification)*: (See page ii)

12. PERSONAL AUTHOR(S): J. Grun and S. Kacenjar

13a. TYPE OF REPORT: Interim

13b. TIME COVERED: FROM ________ TO ________

14. DATE OF REPORT *(Yr., Mo., Day)*: February 17, 1984

15. PAGE COUNT: 16

16. SUPPLEMENTARY NOTATION: This work was supported by the U.S. Department of Energy.

17. COSATI CODES

FIELD	GROUP	SUB. GR.

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*:
Rayleigh-Taylor
X-ray backlighting

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

This abstract

~~We~~ describes a face-on x-ray backlighting method that does not require a dedicated laser beam and a separate x-ray source. This method is used to measure the lateral mass transfer characteristic of the Rayleigh-Taylor instability in ablatively accelerated, laser driven targets.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS ☐

21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL: J. Grun

22b. TELEPHONE NUMBER *(Include Area Code)*: (202) 767-3681

22c. OFFICE SYMBOL: Code 4730

DD FORM 1473, 83 APR — EDITION OF 1 JAN 73 IS OBSOLETE.

11. TITLE

A NOVEL X-RAY BACKLIGHTING METHOD FOR RAYLEIGH-TAYLOR INSTABILITY MEASUREMENTS ON ABLATIVELY DRIVEN TARGETS

A NOVEL X-RAY BACKLIGHTING METHOD FOR RAYLEIGH-TAYLOR INSTABILITY MEASUREMENTS ON ABLATIVELY DRIVEN TARGETS

Much work has been done in recent years to determine the constraints imposed by the Rayleigh-Taylor (R-T) instability on fusion pellet designs. Most of the effort so far has been theoretical.[1] Experiments[2-9,11,12] have lagged behind theory because it is difficult to distinguish between R-T caused effects, such as target shape distortion, and similar effects caused by nonuniform laser beam profiles or preheat. In this paper we describe an experimental method[9] that can make this distinction. This method is both simple and quantitative: i.e., the growth rate of R-T may be inferred.

The R-T instability of an ablatively accelerated pellet shell is thought to occur near the ablation surface where the pressure and density gradients are not collinear.[1] A periodic perturbation of this surface grows exponentially causing dense target material to "fall" into the ablation plasma while distorting the target shape. The growth of the falling protrusion, known as a spike, is fed by mass flow from the surrounding region of the target, known as a bubble. While target shape distortions may in general be caused by phenomena other than R-T,[10] the bubble-to-spike mass transfer and the resulting variations in the target areal density (ρr) are characteristic of hydrodynamic instability.

These considerations have led us to design an experiment that directly measures changes in the areal mass density of ablatively accelerated targets. The targets are carbon foils, about 7 μm thick, with an initial periodic perturbation[2,11,12] of their areal mass density ($\frac{\Delta(\rho r)}{\langle \rho r \rangle} = 0 - \frac{2}{3}$, $\lambda =$ 10–100 μm). Perturbing the targets in this manner provides known initial conditions for comparison to theory and permits controlled experimental access to both the linear and nonlinear phases of the phenomenon. These targets are

Manuscript approved November 28, 1983.

ablatively accelerated by a 5 nsec FWHM, 1.05 μm, 10^{13} W/cm^2 laser beam to 100 km/sec. Up to 23 classical R-T e-foldings are possible under these conditions, depending on the perturbation wavelength.

Areal mass density is measured with face-on x-ray backlighting. In contrast to conventional backlighting which requires a separate laser beam to irradiate the x-ray source, we incorporate the x-ray source <u>into</u> the target. This is accomplished by burying a thin ($\leq$ 0.1 μm) layer of backlighter material beneath the target surface so that it can be excited by the laser beam driver during target acceleration. As in the conventional method, the backlighter x rays may be measured by a streak camera to provide fine temporal resolution in one spatial dimension or they may be observed with a pinhole camera to give a two-dimensional image whose temporal resolution is defined by the duration of the source emission. The backlighter material in this experiment was chosen to be magnesium because it is an efficient emitter of 1.3 KeV x rays and because it has a density similar to carbon, thus minimizing perturbation caused by material mismatch.

The experimental setup is shown in Fig. 1. A perturbed carbon target with a magnesium backlighter layer and an overcoating of styrene (CH) is viewed with three aluminum-filtered pinhole cameras. One camera measures the magnitude and uniformity of the short duration x-ray pulse from the magnesium and the carbon self-emission. The second camera, placed diametrically opposite to the first, records the x-radiograph of the target. Any source nonuniformities can be accounted for during data reduction by comparing identical regions of both the first and second cameras. The third camera is filtered with stepped layers of carbon to calibrate the film on each shot. In addition, on each shot, the timing and duration of the x-ray pulse is measured with an aluminum-filtered MRD 500 photodiode (with its glass window removed).

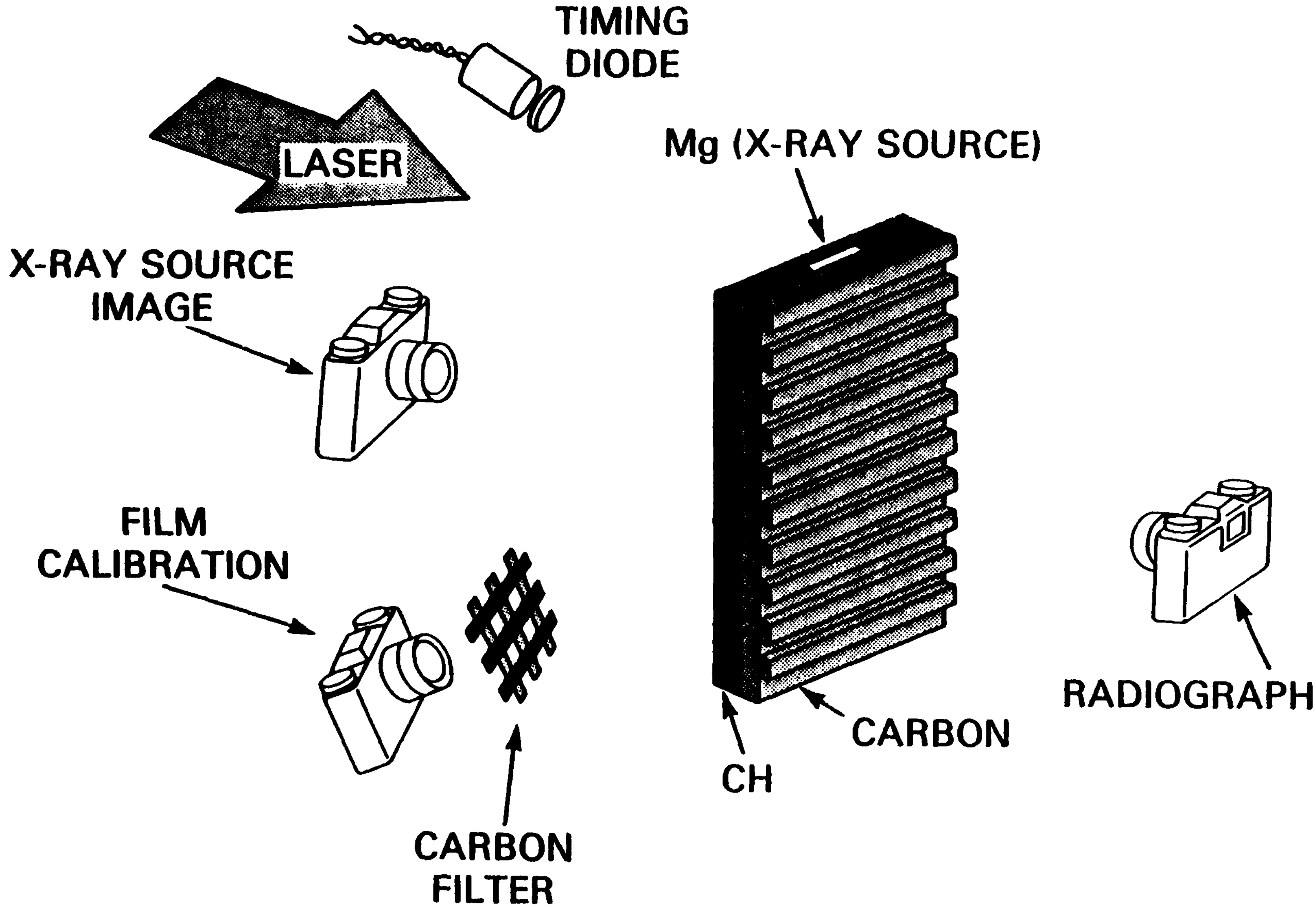

Figure 1 Experimental setup

Figure 2 shows photographs from the three cameras for the case of a target accelerated to 80 Km/sec with a $\frac{\Delta \rho r}{\langle \rho r \rangle} = 0.1$, $\lambda = 50\ \mu m$ perturbation. The radiograph has high clarity and contrast due to the proximity of target and backlighter. Note that the x-ray source (seen from the front side of the target) has a modulation at the same period as the target perturbation. This modulation was small for all cases examined thus far. But if the target were to become very distorted, modulation of the emission from the front surface would increase. One could then account for it by a point-by-point comparison of the source and radiograph images. (Backlighting experiments with a separate source must also account for this rippling of the front surface emission.)

The source and radiograph photos in Fig. 2 are composed of two regions: a dim circular region produced by carbon x rays only, and a brighter rectangular region produced by the sum of carbon x rays and magnesium-backlighter x rays. For most of our data, the ratio of optical densities in the bright and dim regions varied from 2 to 6 depending primarily on pinhole diameter, i.e. location on the film's H&D curve. In general, therefore, it is desirable to subtract out the weaker time-integrated signal. Also, it is useful to calibrate the film directly in-situ and forego x-ray source and film/densitometer models. This is done in our experiment

The basic features of the data reduction are as follows (see Appendix): 1) We use an experimentally verified[13] functional form $\log_{10}(\text{antilog}_{10}(\text{OD}) - 1) = A \log_{10}(I) + B$ for the film's optical density OD versus irradiance I, where A and B are constants. To obtain A we measure OD from images taken through different area pinholes (i.e., different I) and determine the slope of the above expression. B is arbitrary since the units of I are not defined and is set so that OD is small for $I \equiv 1$. This is done separately for the dim and

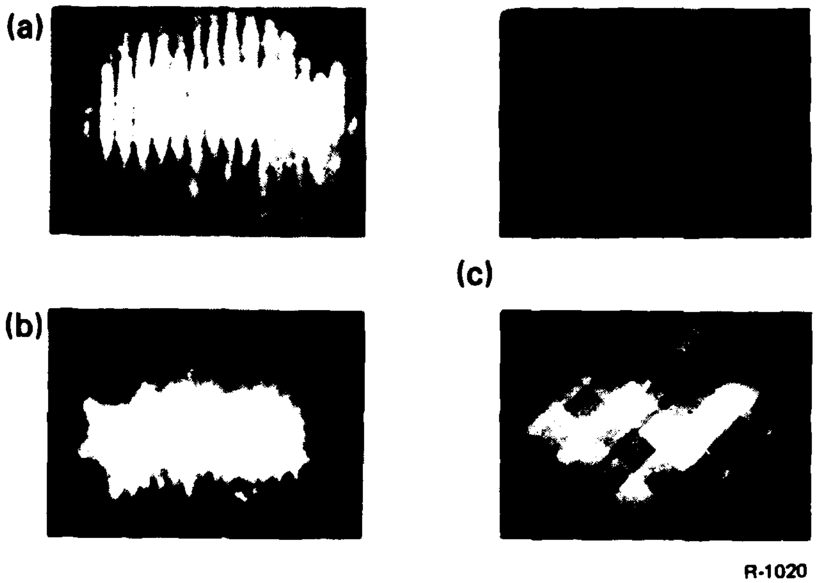

Figure 2 Sample result: (a) radiograph. (b) x-ray source. (c) calibration photographs. This target with a $\frac{\Delta\rho r}{\langle \rho r \rangle} = 0.1$, 50 μm wavelength perturbation was accelerated to 80 km/sec.

bright regions of the film. 2) Cold carbon opacity is used to relate the attenuation of backlighter x rays to ρr. This is valid since the accelerated target is cold($\lesssim$ 5 eV) where it is dense.[14] The opacity is measured utilizing the stepped carbon filter on the calibration camera. 3) Finally, when subtracting the (dim) self-emission from the (bright) total signal we extrapolate the self-emission magnitude, measured near the backlighter edge, underneath the backlighter. We also treat the backlighter pulse as though it was instantaneous.

For this backlighting method to be most useful time resolution is necessary. The backlighter duration is influenced by three factors: the time to completely ablate the backlighter material, the time dependence of x-ray emission as these ions flow away from the target, and temporal smearing due to nonuniform ablation across the target surface. Ablation of the backlighter material occurs on the fastest time scale (about 0.2 nsec, for a 0.05 μm thick Mg layer irradiated at 1×10^{13} W/cm^2). Emission during ion flow takes longer. Using density, temperature, and flow velocity profiles from a hydro code[15] and a simplified expression for line emission[16] we estimate that the backlighter emits for about 1 nsec. Nonuniform mass ablation can arise from the gross shape of the beam profile, local nonuniformities in the beam, or target nonuniformities. The first effect is easy to eliminate by using a backlighter area much smaller than that of the laser focal spot and the second is partially alleviated by plasma thermal conduction smoothing.[17] The exact contributions of local laser nonuniformities and target nonuniformities, if and when they exist, are difficult to estimate. In our initial experiments the backlighter emission varied from 1.5-2.5 nsec.

How sensitive is our ρr measurement to the emission time of the backlighter? To address this question, we have calculated the x-ray intensity on a radiograph by convoluting the finite x-ray pulse duration with the time varying areal mass density of a linearly unstable R-T target using a simple code.[18] We found that the error in the inferred ρr made by neglecting the time dependence of the source is very small - even during the time of maximum R-T growth. For example, only a 25% error is made in $\Delta(\rho r)$ at the laser peak when a 2.5 nsec x-ray pulse backlights a target with and initial $\Delta(\rho r)/\langle \rho r \rangle = 5\%$, $\lambda = 60$ μm perturbation; this error decreases to 15% if $\lambda = 120$ μm. Moreover, if the backlighter turns on later in the laser pulse, when the growth rate has slowed, the approximation is even better.

Finally, we point out some advantages and shortcomings of this method, especially when compared to face-on x-ray backlighting with a separate source. The advantages are: a separate backlighting beam is not necessary; two-dimensional spatial and temporal resolution is possible with simple equipment, x-ray source nonuniformities are easy to unfold during data reduction; and very good contrast is obtained since the target and backlighter are in proximity. On the other hand: the target is more complicated, the instability can disrupt the backlighter (although this has been small so far and can be accounted for in reduction); and time resolution better than 1 to 2 nsec is difficult (or not possible) without a time-resolving detector such as a streak camera or a pulsed channel plate detector.

In conclusion, we have described a simple and novel x-ray backlighting method that is being used to measure mass redistribution caused by hydrodynamic instabilities. Using this method, we have measured an increase of the initial target perturbation $\Delta(\rho r)_o$.[6,7] A detailed presentation of our results will be published elsewhere.

We thank Dr. M. Peckerar, Mr. M. Fink, and Mr. J. Kosakowski for helping to manufacture the targets and Mr. R. Whitlock for providing pinholes and film. We also thank Dr. M. Herbst, Dr. S. Obenschain, and Dr. E. McLean for helping with various aspects of this experiment. Stimulating and useful discussions with Dr. B.H. Ripin, Dr. S. Bodner and Dr. M. Emery are gratefully acknowledged. The technical assistance of Mr. N. Nocerino, Mr. E. Turbyfill and Mrs. B. Sands is also very much appreciated. This work was supported by the U.S. Department of Energy.

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APPENDIX

Our calibration camera provides enough information to calibrate the film and the x-ray source. The procedure is described here.

Calibration Camera

One of the three cameras in Fig. 1 photographs x rays from the target, after these have passed through a grid of carbon fibers: x rays that have passed through 0, 0.81, 1.15, and 1.96 mg/cm^2 of carbon are recorded. This camera contains five pinholes of varying diameter so that five images with different exposure levels are produced on each shot. An example is shown in Fig. 2c.

The film (KODAK 2490) is filtered with 4.5 μm thick aluminum which transmits x rays of between 1 and 1.6 Kev.

Film Calibration

In the foot and straight portion of the H&D curve our film is characterized by[13]

1) $$OD = LOG\,[1 + ANTILOG\,[A\,LOG(I) + B]]$$

where OD is the optical density, I is the irradiance, and A, B are constants. Both these constants depend on the photon energy. B also depends on the units of I.

For simplicity we rewrite equation 1) as

2) $D = A\ LOG(I) + B$, where

3) $D \equiv LOG[ANTILOG(OD) -1]$.

To find A, we note that x-ray intensity is proportional to the pinhole area and utilize the slope of

4) $D = A\ LOG(\text{pinhole area}) + \text{constants}$.

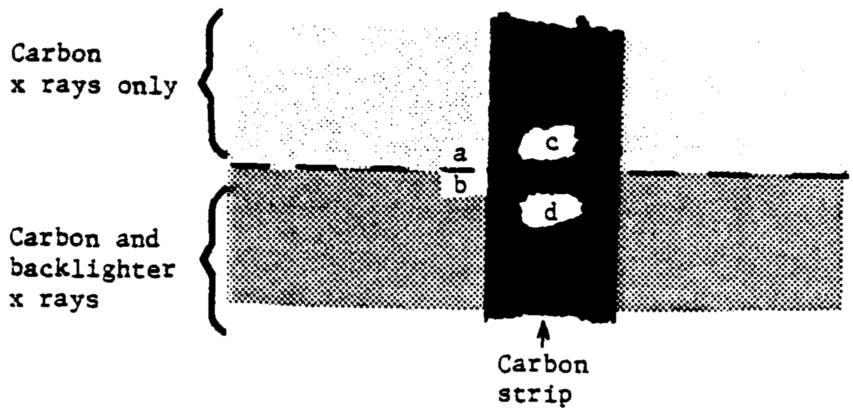
Since the units of I in Eq. 2) are not defined and are not needed for this reduction, the constant B is arbitrary. We set $B = -1$ so that OD is small when $I = 1$.

This procedure is carried out separately for regions of film exposed by carbon x rays only and regions of film exposed by the sum of carbon and backlighter x rays. The resulting coefficients are called A_c and A_s respectively.

Source Calibration

In what follows, the subscript c,mg refers to exposure by carbon x rays or by the magnesium backlighter x rays respectively; the subscript s refers to exposure by the sum of carbon and backlighter x rays; the superscript o, as in I^o, refers to exposures by x rays that have not passed through any carbon; no superscript implies the x rays passed through carbon of areal density ρr.

Consider a region on film exposed as follows:



Then: in region a)

4a) $D_c^o = A_c \mathrm{LOG}(I_c^o) + B$

in region b)

4b) $D_s^o = A_s\ \mathrm{LOG}[I_c^o + I_{mg}^o] + B$

in region c)

4c) $D_c = A_c\ \mathrm{LOG}\ [I_c] + B$

in region D)

4d) $D_s = A_s \, LOG[I_c + I^o_{mg} \, e^{-\alpha\rho r}] + B$

The opacity of carbon (α) to the backlighter x rays is gotten from 4d) after using 4c to solve for I_c. and 4a) with 4b) to solve for I^o_{mg}.

Data Reduction

Having calibrated the film and x-ray source, we proceed to analyze the R-T unstable target. For this we utilize the front (source) and the back (radiograph) cameras. We assume that the backlighter pulse is instantaneous. Also, when subtracting the carbon x rays from the total signal we extrapolate the carbon x-ray magnitude, measured near the backlighter edge, underneath the backlighter. The equation used for this is Eq. 4d) with D_s measured from the radiograph. I_c is gotten from the radiograph also, using Eq. 4c). I^o_{mg} is gotten from the "source" camera using Equations 4a), 4b).

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